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HDL-TEMPO Deionized Water System

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The TEMPO high-voltage (HV) microwave driver at Harry Diamond Laboratories (HDL) is a repetitive pulse generator designed to power experimental microwave generating devices. The Sandia National Laboratory designed and furnished the TEMPO system, which was installed and then extensively modified by HDL. The TEMPO system has a utility section that includes a water processing system to deionize and deaerate the water in the pulse-forming transmission line (PFL). The water processing system is equipped with pumps and directional controls so that water can be transferred to and from the high-voltage PFL tank and an external storage tank. The water can also be independently recirculated in either tank as needed.

This manual covers the complete operation and routine maintenance of the TEMPO's deionized water system at HDL.

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Contents

Contents (cont'd)

Page

Figures

1. Introduction

The TEMPO is a high-voltage (HV), repetitive pulse generator designed to power experimental microwave generating devices. It consists of a resonant pulse-charging transformer powered by a dual-polarity capacitor bank, which charges the water-insulated pulse-forming transmission line (PFL). When the HV air-insulated spark gap fires at or near the peak of the charge cycle, a pulse is delivered from the center output conductor of the PFL to the vacuum diode and microwave load located at the end of the generator opposite the pulse-charging section. Primary power for the capacitor bank is supplied by a commercial dual-polarity power supply, which is controlled from a central station.[1]

The TEMPO system is furnished with a utility section consisting of a 175-psi, 85-scfm air compressor and a water processing system that deionizes and deaerates the water in the PFL. The compressed air is passed through a coalescing filter and water separator before it is directed through the pressure and volume control subsystem that supplies air to the primary capacitor bank switch and the HV Blumlein switch. The water processing system is equipped with pumps and directional controls so that water can be transferred to and from the high-voltage PFL tank and an external storage tank. The water can also be independently recirculated in either tank as needed.[1]

The deionized (D.I.) water system consists of an external storage tank; a water transfer, treatment, and control cart; and interconnecting piping and control cables. The D.I. cart is housed in the TEMPO transportainer (a shed), behind the high-intensity flash x-ray (HIFX) building at Harry Diamond Laboratories (HDL). The shed also houses the system's air compressor and the self-contained deaeration (D.A.) system.

The D.I. system may be operated either with or without the D.A. system. The reverse, however, is not true since the D.A. system requires specific pressure/flow rates from proper setting of the D.I./D.A. systems and interface flow-control valves.

[1]*Gerald J. Rohwein, Pulsed Power Components Division, Sandia National Laboratories, Description and Operating Instructions: TEMPO High-Voltage Microwave Driver, SAND87-0851 (April 1988).*

2. Background

The D.I. system was designed and furnished by Sandia National Laboratories (SNL) as part of the TEMPO pulser contractual effort. The D.I. cart was produced by Pure Solutions, Inc. (PSI), under contract to SNL. HDL personnel installed the system, modifying the installation plan suggested by SNL to include features which were deemed by HDL to be desirable or necessary for the deionized water treatment facility to be functional and reliable. Figure 1 depicts the complete D.I. system as it was finally configured and is currently used.

The system as furnished by SNL was advertised to be self-contained and capable of unattended operation; essentially all system functions were to be controlled at the remote panel. This remote-control panel was installed adjacent to the pulser, which, it was hoped, would minimize the need for trips to the shed (outside the building some distance from the pulser).

However, after some weeks of operation it became clear that the system could not be operated as expected. Operators had to make numerous daily trips to the shed to read or adjust the flow rate, to read or adjust the water resistivity monitor, or, in many instances, just to verify the operational mode by viewing the function lamps which were furnished only on the master control panel. The flow adjustment and monitoring devices, the resistivity monitor/controller, and the master (local) control panel are all located on the D.I. cart.

In fact, a new operator would usually have to check the position of the local/remote selector switch on the master panel just to determine whether the remote panel was active, since there were no indicator lamps (other than the flow alarm, which was disconnected by PSI because of an improperly sized flow-switch) to tell him what was going on.

Also, there was severe water-pipe "hammering" each time the stop button was pushed, because the electric valves closed at the same time the main pump stopped; normally this went unnoticed since it was barely discernible at the remote-control station.

As a consequence of these deficiencies and limitations, a plan was devised to implement changes to the original system so it could operate essentially unattended from the remote panel. Trips to the shed would then be

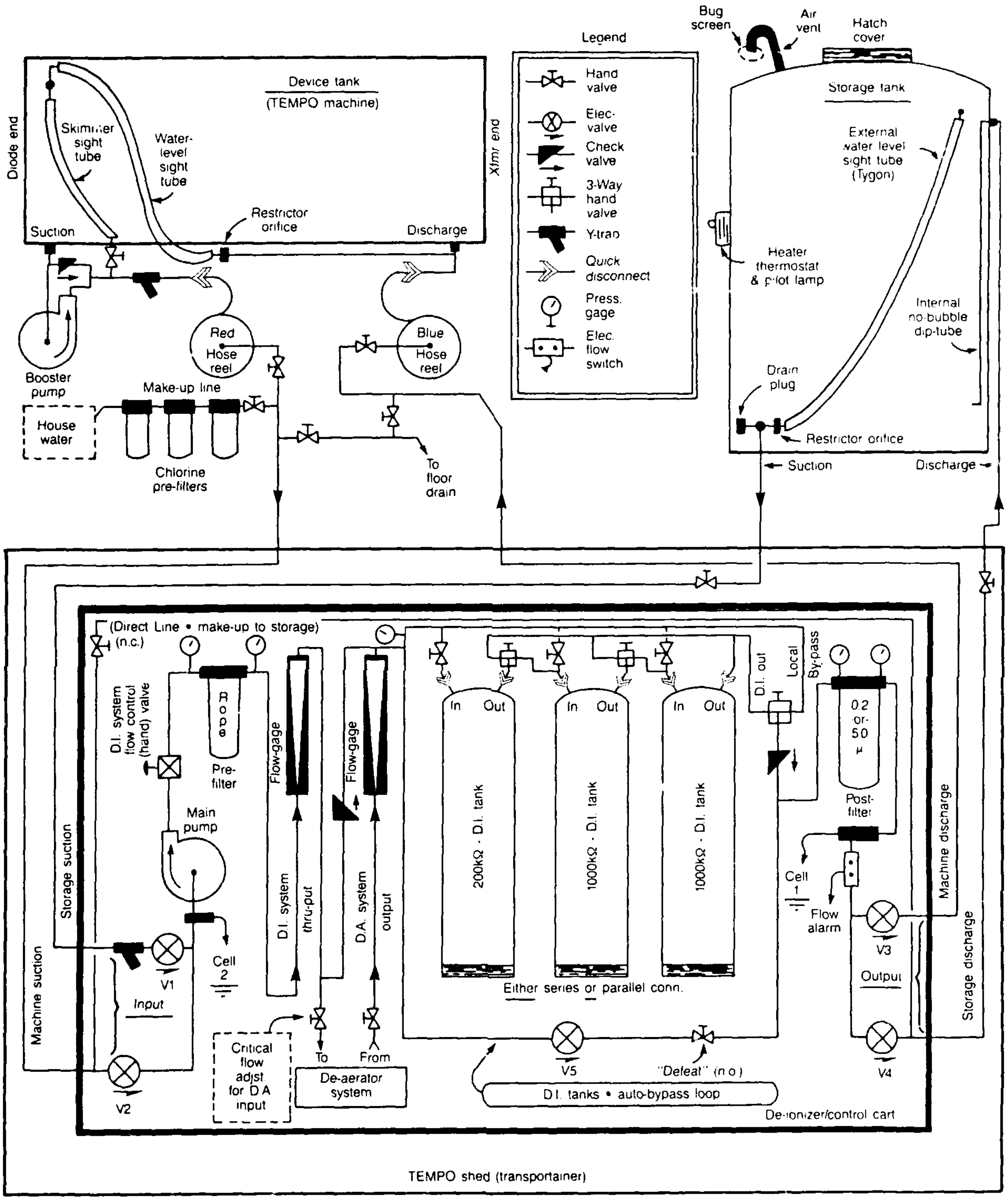


Figure 1. HDL-TEMPO D.I. water system — flow and piping diagram.

necessary only to check on D.I. tank output resistivity, to investigate flow-rate changes from clogging of filters, and, on rare occasions, to operate the D.A. system manually either to adjust flow rate or to deaerate the water in the storage tank. These changes are described in section 3.2, Subsequent Modifications.

3. Modifications

3.1 Initial Modifications and Additions

HDL personnel undertook a number of changes to the system during the installation phase.

We removed the four hose reels from the D.I. cart to allow more room for piping on the cart and to facilitate future movement of the pulser; two of the hose reels were used as the final connection point for the pulser tank fill and drain lines.

Also, it was apparent that water-level gages were desirable, so we installed Tygon tubing as a sight glass on both the pulser and storage water tanks. The tubing on the storage tank freezes in winter, but suffers no damage.

A viewable skimmer capability was added to the pulser tank with Tygon tubing and a valve, to facilitate the removal of debris (plastic chips, etc.) floating on the water surface.

We installed an internal dip tube on the storage tank discharge port to, it was hoped, eliminate this area as a source of trapped air bubbles, since air bubbles were known to be a problem if they were occluded inside the pulser tank.

3.2 Subsequent Modifications

In accordance with the plan mentioned above, the D.I. system controller and piping were completely revised. The result has exceeded expectations, with only about one trip per week required to the shed to check on filter clogging or to monitor the output resistivity level of the D.I. tanks.

Also, it was possible to automate (recirc-device function only) the D.A. system operation with four (of five) relays which had been wired for selector switch position "C," but were not used by PSI for this application. Indicator lamps were added to the remote-control panel to show when the D.A. system was running, whether in automatic (recirc-device) or manual operating modes.

The first control system modification was to exchange the two functions, fill and recirc-storage, on both the master and remote-control panels. This was done simply by switching labels and reprogramming the EPTAK-100 process computer that provides logical and physical control of the D.I. system. The benefit is that now the system is relatively fail-safe, in that recirc-storage is on the unwired function pushbutton which is always "on," regardless of actual switch setting. Since there always will be water in the storage tank, barring some disaster, an accidental start should cause no unexpected problems.

A related modification was the addition of four indicator lamps to the remote panel to show which function was in use. Also, by wiring of the fifth unused relay for switching control, an indicator lamp was added at the top of the remote panel to show the status of the local/remote selector switch, where on means the remote panel is active.

The flow-switch assembly, which was designed for 8- to 10-gal.-per-min (GPM) flow rates, was internally modified with PVC pipe and epoxy to reduce the throat cross-section. This change, plus the addition of an epoxy "sail" to the flow-sensing vane, resulted in a flow-switch which activates reliably at 4 to 5 GPM and stays on down to about 1.5 GPM. Thus the flow protection circuitry was made to function as originally designed, and has been working reliably ever since.

A bypass switch was added to the flow-switch circuitry inside the master control panel, for (local) use, only if necessary, when purging air during filter and D.I. tank changes. This switch is normally off.

The water pipe "hammer" was eliminated by reprogramming of the EPTAK-100 computer. One of the computer's timers was used to delay valve closure time, relative to main-pump shutdown.

The EPTAK-100 was also reprogrammed for a timed on/off cycle (auto-cycle) for the recirc-storage function only. This provides the capability to periodically circulate water in the storage tank lines during the winter, automatically, out-of-hours, to prevent freeze-ups. This function must be started manually, and continues until stopped manually.

The booster pump, under the TEMPO (device) tank, was reprogrammed and rewired so it may operate any time the device-suction valve is opened by the EPTAK-100, but runs only under manual control. This pump is used mainly to purge air from the lines and main pump (which is not self-purging from the device tank) after a "drain-dry" condition, or after Y-trap cleaning, so the pump actually operates by a (new) switch on the pump control box, adjacent to the (new) lamp which indicates selection status. Do not use the booster-pump during the recirc-device function, since such use will upset the D.I./D.A. flow-rate balancing, which is set for main-pump flow only.

We removed the electric valve from the booster-pump system piping loop since it was not necessary; the check valve was sufficient to prevent back-flow during booster-pump operation. A bypass loop was installed around the D.I. tanks, with the use of this valve, to provide for EPTAK-100 control over the D.I. tank. An indicator lamp added to the remote-control panel showed the status of this bypass valve. Then we reprogrammed the computer to auto-bypass the D.I. tanks during the fill, drain, and recirc-storage function(s). A local hand-valve was provided to defeat the auto-bypass mode, if needed.

Indicator lamps were installed on the remote-control panel to show the status of the D.I. water flowing in the system. These lamps mirror the above/below set-point status lamps on the front panel of the Thornton model 832 resistivity monitor, via a relay (undocumented) inside the Thornton meter cabinet. Thus, by proper conductivity cell selection, and by proper adjustment of the Thornton meter set-point control (both on the master control panel), one can determine whether the resistivity of the D.I. water flowing through the TEMPO tank is adequate for carrying out tests without any trips to the shed, once the initial settings are made.

The final modification involved nearly complete replumbing of the D.I. cart, changing the point, flow-wise, at which the D.A. system received and returned water to the D.I. system. Originally, this point was ahead of the D.I. tanks with the flow gage down under the master control panel, where it was difficult to read. With this configuration the D.I. system, running alone, would routinely achieve an 8- to 10-Mohm-cm tank water resistivity after 3 to 4 hr of operation; however, including the D.A. system in the flow-loop would reduce the maximum resistivity to no more than 3 Mohm-cm, even after more than 24 hr of continuous running.

Since we needed at least 5-Mohm-cm water circulating in the TEMPO tank during firing, we undertook a complete revision of the D.I./D.A. interface portion of the plumbing system, as recommended by SNL. The D.A. flow-gage was relocated next to the D.I. flow gage to facilitate system flow-rate adjustment and monitoring. The D.A. input shutoff ball-valve has now become another critical flow-balancing adjustment (as indicated on fig.1), in addition to the flow-balancing valves described in the D.A. system operations manual. This valve has become important because of the flow-wise relocation of the flow restrictive D.I. tanks, which previously were ahead of this tap-off point.

The results of this modification have exceeded expectations, since the deaerated and deionized TEMPO tank water now easily surpasses the 5-Mohm-cm level required for shooting. It takes slightly longer than before to achieve this level, due to the "poisoning" effect of the D.A. system, but the D.I. tanks have proven adequate to the task, since there have been no long-term degradation effects observed. After one year's operation with the same set of tanks, the three-tank series output capability is about 15-Mohm-cm (with about 3-Mohm-cm input) at the normal flow-rate of 5 GPM, with the D.A. system operating.

4. Basic Operations

4.1 Control System Overview

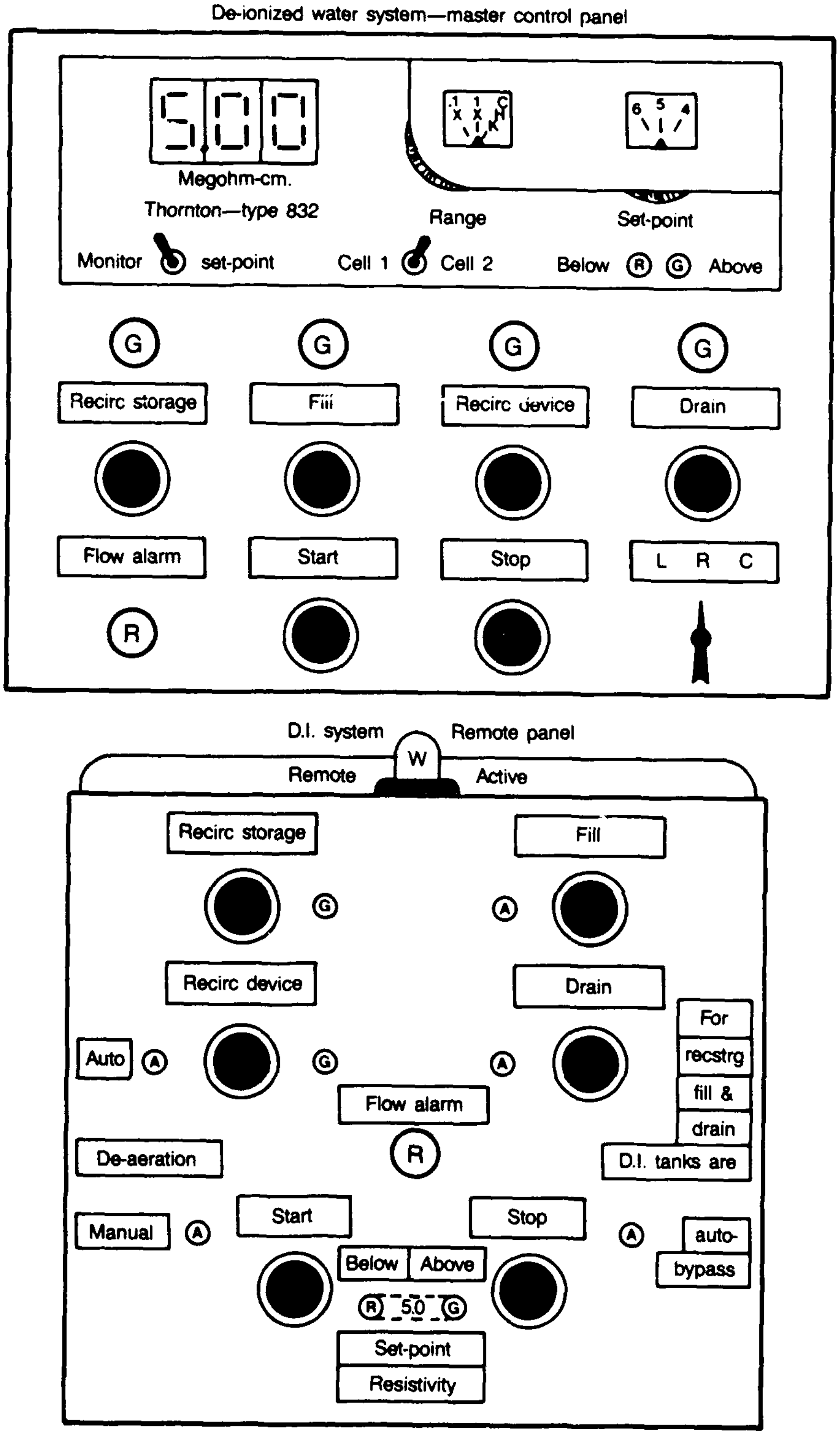
As we mentioned previously, the TEMPO D.I. system is controlled by function-select pushbuttons and by start and stop pushbuttons on both the master (local) and remote-control panels. These pushbuttons control the logic of the EPTAK-100 process computer inside the master control panel, which performs the actual physical operation of the system valves, pumps, and interlocks. The function-select buttons are push/push type; that is, they stay on (in) or off (out) until pushed again, whereas the start and stop buttons are momentary-type, activating only when pushed. Unfortunately, the function-select buttons were not furnished with internal pilot lamps, so it is necessary to look at each one very closely to determine its state. This is one of the reasons for the addition of function indicator lamps to the remote panel; notice, however, that these lamps show selection status only after the system has been started.

Figure 2 depicts both the master (top) and remote (bottom) control panels as they appear to the operator. The remote panel is on the wall, adjacent to the TEMPO pulser tank; the master panel is part of the D.I. cart.

The stop pushbuttons are always active on both panels, regardless of which control panel is selected (to be active) by the local/remote selector switch on the master control panel. The function-select and start pushbuttons are active only on the selected panel. Both panels have a flow-alarm indicator lamp, which is always active on each panel. This lamp is activated by a no-flow condition of more than 8-s duration (8 s chosen for D.A. vacuum-pump protection) and is latched on, once activated; it can be reset only by manual activation of either stop button.

The function-select pushbuttons should always be left off (out) when not in use, on both panels. The recirc-storage button is not actually wired (binary control = 00), but convention is to leave it in (on). In any event, with the other function(s) normally off, an accidental start will be accommodated without difficulty, since the storage tank always contains sufficient water to support recirculation.

Figure 2. HDL-TEMPO D.I./D.A. system control panels.



Also, after pushing the stop button, do not change the state of a function-select pushbutton until the associated indicator lamp goes out. The 4- to 5-s delay is caused by the delayed valve closure, which will be short-cycled by premature function-select changes.

The flexibility of control system reconfiguration has been a most useful, and appreciated, built-in capability. This feature, a consequence of the programmability of the EPTAK-100 computer, has been mentioned previously and was recently used to add two more refinements to the control system logic, without any effort other than devising a new logic diagram and modifying the program. Figure 3 is the control system ladder (logic) diagram currently in use. The complete program which implements this logic is contained in appendix A, together with listings of the I/0 assignments, the relay assignments, and the timer assignments.

The first modification was the addition of a blinking function lamp feature to help conserve lamp life and to make the operating function more visible. A further benefit arising from this implementation is that one can now distinguish whether or not the main pump is running during the programmed timer (auto-cycle) mode of the recirc-storage function because the *auto-bypass lamp* goes out and the function lamp goes to steady-state while the pump is off. Also, the valve open/close time, delayed with respect to main-pump operation, is clearly visible at the panel.

The recirc-device function lamp does not blink, since the automatic D.A. feature, which is initiated by this circuit, requires a steady-state condition for relay activation.

The second modification was the addition of two separate modes (Mode 1 and Mode 2) of operation for the fill, drain, and recirc-storage function(s). We did this by noting that the start button is always active during operation. Thus, by providing for logical selection, we could use the start button to initiate a secondary mode of operation. Mode 1 is the primary (auto-bypass) mode, as indicated on the remote panel for these three functions.

Mode 2 may be selected any time the main pump is running, as shown by the blinking of the function lamp, and results in the closing of the D.I. tank auto-bypass valve for all three functions; in recirc-storage, the (auto-cycle) timer programming is also disabled.

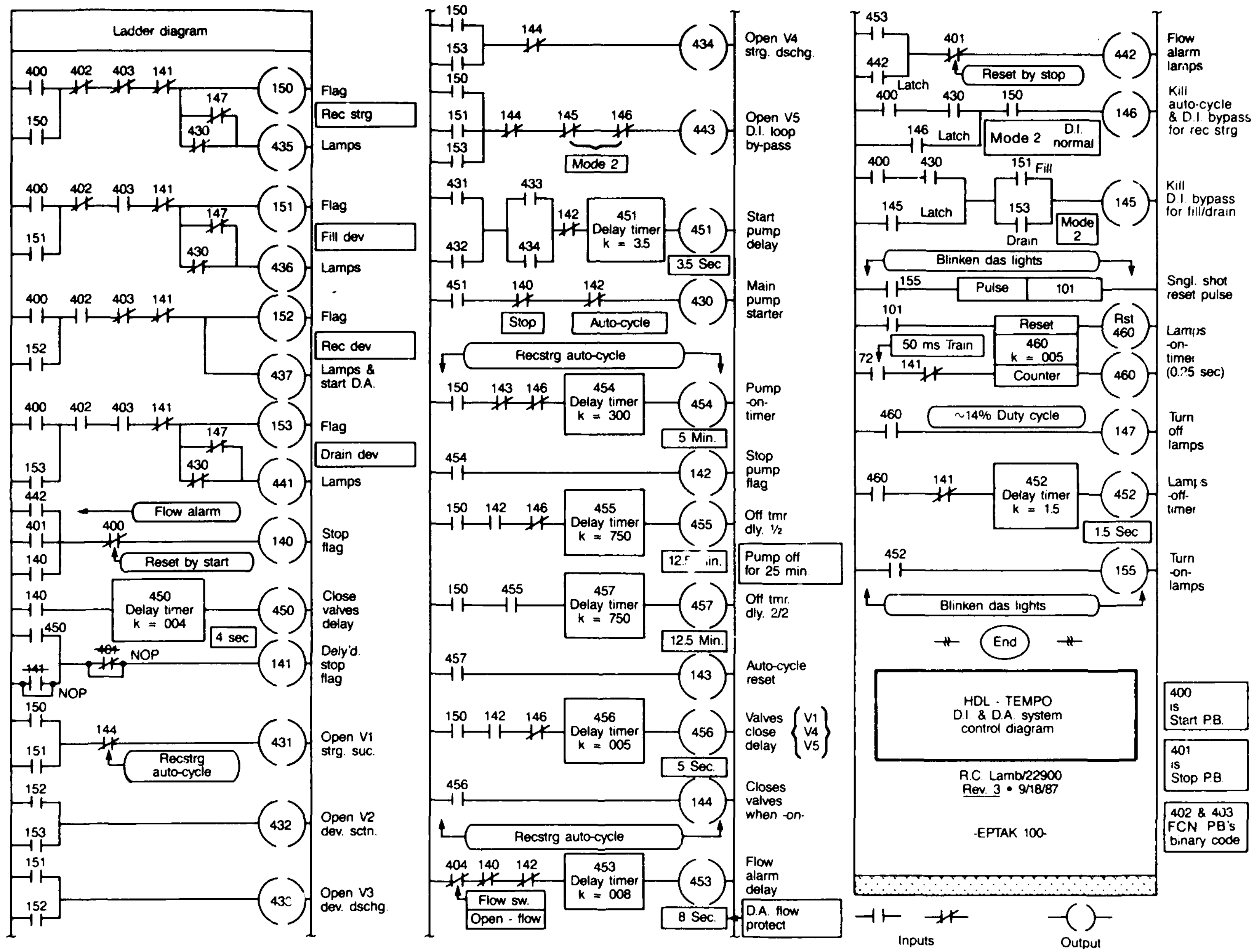


Figure 3. HDL-TEMPO D.I. system — EPTAK-100 I/O and logic diagram.

So now it is possible to fill or drain the device tank through the D.I. tanks, or to continuously deionize the storage tank water should that be desirable; all without any trips to the TEMPO shed. Mode 1 operation is recovered by stopping and restarting.

4.2 Master (Local) Control Panel

The master control panel on the D.I. cart in the TEMPO shed is used while purging air from the main pump after filter or D.I. tank changes, or for flow-rate adjustments in conjunction with local (manual) operation of the D.A. system. This panel must be selected by turning of the "L-R-C" switch to the "L" position. A flow-alarm bypass switch is inside this panel for use, only if necessary, during low-flow conditions that may occur during air purging. This bypass switch must be left in the off position when not being used under direct local operator control, since it bypasses the flow switch (which is the only protection against no-flow damage to the main pump and especially against damage to the liquid-ring vacuum-pump in the D.A. system).

Also inside this panel is the EPTAK-100 computer together with its programming (pendant) console and the bank of (8) external relays. These relays supplement the logical control of the system, normally provided by the I/0 modules (located on the face of the EPTAK-100) and the computer's internal relays.

The Thornton model 832 resistivity monitor is built into the front cover of the master panel, and is normally configured as shown on figure 2. Set-point can be adjusted if the switch is held and the dial rotated to obtain the desired readout. The system is supplied with two conductivity cells, either of which may be selected with the cell-1/cell-2 selector switch. As shown on figure 1, cell-1 monitors the output of the D.I./D.A. system, whereas cell-2 monitors water condition at the input to the D.I./D.A. system. Cell-2 is the normal selection, as it indicates TEMPO (device) tank water quality during recirc-device operation.

4.3 Pulser (Remote) Control Panel

From the remote control panel, on the inside wall of Bldg 504 adjacent to the TEMPO device, the tank water-level gage and the booster-pump controls can easily be seen. The status lamp on top of this panel reflects control selector switch position, where lamp off equals local "L" and on equals remote "R" selection at the master control panel. For this panel to be active the status lamp must be on, with the exception that the stop pushbutton and the flow alarm are always active.

The open circles on figure 2 indicate pilot lamps, with the inscribed letter signifying lamp color: amber, green, red, and white. Lamp color also indicates the attention level required for the function or mode, with red meaning immediate attention required, amber meaning occasional attention required, and green meaning that unattended operation is acceptable. An exception to the significance of lamp color is the set-point lamps, which reflect water quality only.

4.4 Setting Base Flow-Rate

All flow rates must be set from the master panel, since this is the only place where one can view the flow gage(s) and adjust the manual flow-control valve, which is just above the main pump.

Normally, the easiest way to set the base flow-rate is recirc-storage in Mode 1, adjusting the flow-control valve for about 7.6 (7.5 to 7.7) GPM flow. This must be done with relatively clean filters and, preferably, with the storage tank at least half full, as indicated by its external sight gage. Filter condition is indicated by the differential pressure (gages) on each filter where, for the pre- and post-filters, it should be less than 4 psig at 5 to 7 GPM. Then shift to Mode 2 operation and verify that the flow rate with the D.I. tanks (series-connected) in the flow path is about 5.1 (5.0 to 5.2) GPM. For further refinement of this procedure see section 5.4 (setting D.A. flow rate).

From this procedure it is apparent that the reason for using Mode 1 for filling and draining is the decreased time to perform these functions. Further time saving is possible during draining *only* by running the booster-pump, which increases the flow rate to about 8.8 GPM. However, this procedure increases the risk of air being ingested into the system as the tank water depth gets down to the 5- to 6-in. level above the tank bottom (see sect. 4.7).

4.5 Recirc-Storage

There is little to say about the recirc-storage function since the operation is straightforward and little used except in the winter, or for flow setting as described above. Occasionally during the late summer it may be necessary to recirculate the storage water in Mode 2, since the water quality tends to degrade below 1 Mohm-cm; this low water quality forces longer recirc-device times once the water is in the TEMPO tank.

4.6 Fill

The fill function is normally performed under Mode 1 unless the storage water quality is well below 1 Mohm-cm. There seems to be little difference in recirc-device time whether or not the incoming water is routed through the D.I. tanks, but the time to fill increases by 50 percent if Mode 2 is used. Fill-time averages about 50 min; when the water level approaches the lid liner, one should shift to Mode 2, thereby reducing the tendency to trap air-pockets under the lid by filling at the slower rate.

The filling process must be stopped manually by the operator once the lid is completely covered, since there is no automatic level-sensing shutdown mechanism.

4.7 Drain

This function is normally performed in Mode 1, since the water is usually well above 5 Mohm-cm when transferred. Also, to expedite draining, the booster-pump may be run manually with the skimmer valve closed first, until the water level gets down to about 4 in. above the bottom tank liner. At this point the booster-pump should be turned off. As the water level approaches the surface of the bottom tank liner one should shift to Mode 2. The slower rate allows better control, to lessen the chance of sucking in air. The water level should not be allowed to get below about 1.5 in. from the tank bottom or air will be ingested and a flow-alarm will result.

It is difficult to do the final draining (to get a dry liner, but not a dry tank) without first removing the lid, since the water-level sight gage does not respond rapidly enough to reflect actual depth in the small volume of water at each end of the bottom tank liner.

If a dry tank is needed, the best way is to open the floor drain valves (with D.I. system off) on both the suction and discharge lines and "waste" these last few gallons. Recovery from this condition (which puts air into the lines) is covered in section 5.3.

4.8 Recirc-Device

This function is used both to prepare the TEMPO machine for shooting and during shooting. Operation is straightforward once the proper flow-rate balance (see sect. 5.4) has been established for the D.I./D.A. system, which, of course, has been set previously. The deaeration auto indicator lamp should come on at main-pump start (about 4 s after start) and stay on until the function is manually stopped.

Occasionally, the D.A. auto lamp will flash but not stay on. This is caused by a latching failure on the interface relays and can usually be corrected simply by stopping and restarting.

Never run the booster-pump during recirc-device because the D.A. system flow will become unbalanced, with a high probability of damage to that system.

The auto lamp reflects the actual control status of the D.A. system and will go out if, for some reason, the D.A. system shuts down independent of the D.I. system. The flow-alarm will shut down both systems, reliably.

Also, the D.A. system is quite effective in removing bubbles from the TEMPO tank (somewhat dependent on atmospheric pressure). Normally, overnight operation will revolve the worst of the trapped under-lid air-bubbles, if that should become a problem during prolonged shooting.

5. Special Operations

5.1 Skimming TEMPO Tank

The water-surface skimming capability, built in at the outset, has proved most useful in removing debris floating on the water, especially after maintenance and repair operations inside the TEMPO tank.

To use this feature, you must first fill the tank so the skimmer port is about half-covered, with the lid off. Then start the recirc-device function and open the skimmer valve. Flow will be seen in the skimmer sight-tube and in about 45 min the water surface will be spotless. Do not run the booster-pump with the skimmer valve open, as this valve is on the output side of the booster-pump.

5.2 Purging Air from Main Pump

The main pump, located on the D.I. cart, will not purge itself unless there is some head-pressure at its input. If the storage tank is full, this pump will usually purge itself after a few flow-alarm/restart sequences; in fact, if all the water is in storage, this is the only method of reestablishing flow. This procedure can be done from the remote panel, but if not successful after half a dozen tries, then it should be done from the shed, possibly with the aid of the flow-switch bypass.

Also, an air bleed valve has been added to the pump, which you may use in conjunction with opening the electric storage-suction-valve by hand, to allow storage tank water to flow up to the pump inlet.

It is a good idea when purging air to use the manual (local bypass, see fig. 1) capability of the D.I. tanks to prevent filling these tanks with air bubbles (which will cause additional flow-alarms during subsequent operation), otherwise air can get into the D.I. tanks during purge operations because there is always a small flow through them, even when the auto-bypass valve is open, from the slight differential pressure across the check-valve, which prevents it from closing completely. This is one reason the storage water quality is higher during the winter, when the "anti-freeze" auto-cycle is in use, compared to the summer, when there is very little storage tank activity.

5.3 Purging Air with the Booster-pump

The booster-pump was added to the system by SNL to overcome the self-purging deficiency of the main pump, and was envisioned as always being on any time the device-suction valve was open. This function has been modified as described previously, since experience has shown that the main pump works properly once air has been eliminated from the system suction piping.

The booster-pump is used to purge air from the suction piping between the device tank and the main pump. You do this by first filling the device tank to the 7- to 9-in. level (above tank bottom), so that sufficient water exists to perform the operation. Then, if it is known that a lot of air exists in the piping, such as after a "dry-tank" drain-down, it would be a good idea to manually bypass the D.I. tanks (see sect. 5.2).

Next, select the drain function and start the system; immediately (before the function lamp starts to blink) manually start the booster pump. Now watch the flow-alarm closely and if/when it comes on, immediately stop the booster-pump. Then reset (stop) the D.I. system and recycle this complete process until the flow-alarm fails to come on, indicating that all air has been purged from this part of the system.

At this point, it is a good idea to operate the fill, recirc-storage, and drain function(s) a few times to stabilize the system, since some small air bubbles may be trapped in and around the various valves and tees. Should a flow-alarm occur at this time, it usually will yield to a few stop/restart cycles.

5.4 Setting D.A.-Interface Flow-rate

The D.A. system manual states that the system throughput is limited to about 3.5 GPM; however, at HDL/TEMPO we have succeeded in raising it to about 4.6 GPM, which greatly facilitates D.I. and bubble-removal operations. We have done this by judicious tuning of the D.A. flow and bypass valves in concert with careful adjustment of the D.A. system inlet ball-valve (indicated as critical on fig. 1). Normally, these settings should not require further adjustment, but if they do, then you must refer to the D.A. system manual in addition to what is stated here.

Once the base flow rate has been established by the procedures of section 4.4 you should fill the device tank (or nearly so) so that the pressure head will be close to that during actual operation under recirc-device. Next, transfer operations to the master control panel and start the system in recirc-device function.

After the D.A. system has stabilized (1 to 3 min) the D.A. output flow-gage should read about 5 GPM and the D.I. throughput flow-gage should read either slightly above or below this rate, depending on whether the D.A. vacuum column is filling or emptying. There should be about 0.2 (0.1 to 0.3) GPM differential between these two gages for the D.A. system to maintain its fill/drain column function without running dry or overflowing. It takes about 15 to 20 min for a complete column cycle.

The switch-over is observed as a rise in flow rate on the D.A. output flow gage when the column switches to pump-out mode (and conversely for column fill mode), with a corresponding but opposite change in the D.I. throughput flow gage. The D.I. system flow control valve should be fine-tuned to obtain these conditions. Also, D.I. main-pump output pressure, as read on the pre-filter input gage should be about 40 psig if all is well.

Note that the pre-filter should not show more than a 5 to 6 psig pressure differential at about 5 GPM; otherwise it needs to be changed. Pre-filter clogging is about the only thing that routinely affects the D.I./D.A. flow-balancing and, therefore, should be checked weekly.

Finally, remember to check the small flow gage on the D.A. system cart to be sure, at all times during these adjustments, that at least a 0.5 GPM flow rate exists to the liquid-ring vacuum pump — this is critical. You may fine-tune the D.A. system main flow valve (behind the column) to maintain this flow rate, while maintaining about a 4.5 to 4.6 GPM flow through the D.A. system.

5.5 Make-up Water and Procedures

The best way to add make-up water to the system is to deionize the water before adding it to the storage tank. You do this by first running the water from the make-up source shown on figure 1 directly into the pulser tank, preferably with the skimmer valve open. The tank should be nearly empty so that only the make-up volume need be run through the D.I. system. Add the water slowly, watching the flow through the chlorine pre-filters, until at least 6 to 8 in. (minimum for recirc-device) have been added to the device tank. The device tank calibration is about 12 gal./in. above the bottom liner; about 30 to 45 min of slow filling yields 50 to 75 gal. of make-up water.

Close the skimmer valve (if open) and recirc-device until the water quality reaches at least 2 Mohm-cm, which may take as long as 4 to 5 hr. Then, either transfer the water to storage or finish filling the machine, as required. The direct makeup line, shown on figure 1, was used only for the initial storage tank filling and should not be used now, as there is no point in contaminating the system piping or the storage tank with raw water.

To have a sufficient conditioned water reserve, you should endeavor to have a "full" storage tank (with all the system water in storage), with the level, as viewed on the storage tanksight-gage, at the 5-ft mark. Then, when the device tank has been filled, the storage tank should show about 2.5 ft of water remaining.

5.6 Winter Versus Summer Operation

During the winter, in below-freezing temperatures, it is possible for the storage tank lines to freeze, preventing water transfer. These lines are insulated, but not furnished with heat tape, although the storage tank has a band heater, thermostat, and pilot lamp. The outside water (PVC) lines have frozen on occasion without suffering permanent damage, although TEMPO operations have been curtailed temporarily.

The TEMPO shed is maintained at, or above, 60°F during the winter by two heat sources. The primary heat source is the air compressor, which is kept on standby when the TEMPO device is not being fired; the second is a thermostatically controlled space heater, which is used only during cold weather. The air-compressor cycles about every 12 min, when on standby, and supplies a significant amount of heat to the shed. Heat tape has been applied to the water lines between the shed and Bldg 504, which houses the TEMPO pulser.

The storage tank lines are protected from freezing by the auto-recirc-storage capability described in section 3.2. Thus, in freezing weather, all that is necessary to ensure continuity of shooting operations is to start the recirc-storage function before leaving for the night or weekend, and to stop the function upon return to work.

6. Maintenance

6.1 Pre-filter and Post-filter

These filters should be regularly checked for clogging — say every week or two. The pre-filter requires the most frequent changing, whereas the post-filter may last for a year or so. The pre-filter element is a "rope" type and has been very effective in removing even very small particulate matter — so much so, in fact, that the post-filter rarely requires changing.

The pre-filter requires changing when the differential pressure across the element exceeds 5 to 6 psig at about 5 GPM flow rate. At this point, the output pressure drop is enough to adversely affect the operating flow balance of the D.A. system. The post-filter is normally used with a 5-μm element and would require changing whenever its pressure drop exceeds, say, 5 to 10 psig, or if a noticeable backpressure effect is observed on the D.A. system output.

The D. I. tank supplier (Millipore) has suggested that a 0.2-μm post-filter would be used to inhibit algae growth in the storage tank, should this become a problem.

6.2 Y-Traps and Suction Screen

SNL furnished the Y-traps to (it was hoped) eliminate the problem of plastic chips lodging in the seats of the electric valves, on the suction side of the system (especially the device suction valve). This has not been a problem since the traps were installed, but was a severe problem earlier. These traps rarely require cleaning, under the present operating conditions, but should be checked periodically, especially if some unknown flow-related problem arises.

The tank Y-trap is also a convenient place from which to perform a "drain-dry" operation, since a much smaller amount of air is left in the lines for subsequent purging.

A fine screen has been added to the suction device port of the device, in the floor of the pulser under the diode, where it is not easily seen; however, this screen should be checked if inexplicable suction air or flow problems arise. The screen was added after chunks of Carborundum resistor were found lodged inside the booster-pump impeller.

6.3 Electric Valve Cleaning

At one time, cleaning the seat of the electric valve in the device suction line was an altogether too frequent task. The addition of the Y-traps has eliminated this problem, to all appearances, since there has been only one occurrence since.

The problem was evidenced by unexplainable flow alarms in recirc-storage. These were traced to air in the device suction line (while the pulser was drained, but not dry) from a leaking electric valve, which was found to have plastic chips lodged under the seat. This leaking valve allowed the main pump to draw water from the pulser tank at the same time it was recirculating the storage water, until finally air was available at the pump intake port in sufficient amounts to affect the flow switch, especially on startup.

Cleaning the valve seat is fairly straightforward, once you know how to disassemble the body. You can dismantle the valve by removing the four through-screws (located at the corners of the grey plastic body) that hold the black plastic operator module to the valve base. The cover containing the electrical connector should not be removed; just unscrew and remove the connector, otherwise leaks may be created which are troublesome to correct.

6.4 D.I. Tanks (Millipore Contract)

The D.I. tanks and the header piping system were furnished by Millipore Corp., under contract to HDL. As shown in figure 1, the header piping system provides for either series or parallel connection of the three D.I. tanks. The normal operating configuration is for series flow, since this yields higher resistivity water and the throughput flow rate is well matched to the rest of the system.

The system has been operated with the D.I. tanks in parallel and the D.A. system off (both manual operations), when it was necessary to raise the resistivity of the pulser tank water quickly. In this mode, it took less than 1.5 hr (normally about 3 to 4 hr) to raise the resistivity from about 1.5 to 5 Mohm-cm, with a (throughput) flow rate of about 7.5 GPM.

7. Vendor Information

Sandia National Laboratories (SNL)
P.O. Box 5800
Attn: G. J. Rohwein, Division 1248
Albuquerque, NM 87185
(505)846-5535

Pure Solutions, Inc. (PSI)
7800 Lomas Boulevard, NE
Albuquerque, NM 87110
Attn: Bruce Larson (GM)
(505)265-8777

Millipore (Millipore Water Systems)
7600 Penn Belt Drive
Forestville, MD 20747
(301)420-9000

Appendix A. — Eptak-100 Hardware and Software Assignment Sheets

Appendix A contains the program that implements the control system logic for the EPTAK-100 as refined by Robert Lamb of Harry Diamond Laboratories.

Contents

APPENDIX A

A-1. I/O ASSIGNMENT SHEET

APPLICATION: HDL- TEMPO: D.I. SYSTEM CONTROLLER (R. C. [illegible] 7/17/87)

START	STOP	FCN. (1)	FCN. (2)	FLOW SWITCH	LAMP DRAIN	LAMP FLOW ALARM	VALVE V5	T 444 414	
								T 445 415	
o	o	o	o	o	o	o	o		
X400	X401	X402	X403	X404					
					Y441	Y442	Y443		
Y430	Y431	Y432	Y433	Y434	Y435	Y436	Y437		
MAIN PUMP	VALVE V1	VALVE V2	VALVE V3	VALVE V4	LAMP RecStrg	LAMP FILL	LAMP RecDev	T 446 416	
								T 447 417	
o	o	o	o	o	o	o	o		

Notes: 1. FCN.(1) and FCN.(2) are wired to the function select pushbuttons such that the control coding is binary, as follows:

FCN. Select pushbuttons are push/push type: in = on out = off				402	403
	Rec Strg	(No actual wire)	Always sets	ϕ,	ϕ
	Fill		Always sets	ϕ,	1
	Rec Dev		Always sets	1,	ϕ
	Drain		Always sets	1,	1

Thus: fill + rec dev ⇒ drain

2. The indicator LED's on the I/O modules (shown as o) are -ON- when the module is active.

3. X--- = input module(s) → -| |- or -|/|- on ladder diagram.
   y--- = output module(s) → -( )- on ladder diagram.

APPENDIX A

A-2. EPTAK-100 CONTROL RELAY ASSIGNMENT SHEET

APPLICATION: HDL-TEMPO: D.I. SYSTEM CONTROLLER (REV.3) [R.C. Lamb 9/17/87]

NON-RETENTIVE		RETENTIVE WITH BATTERY BACK-UP (non-retentive otherwise)	
RELAY ADDRESS	FUNCTION	RELAY ADDRESS	FUNCTION
100		140	STOP FLAG
101	(S.S. PULSE OUTPUT) RESET COUNTER # 460	141	DELAYED STOP FLAG
102		142	STOP PUMP FLAG
103		143	RESET - AUTO CYCLE
104		144	VALVE CONTROL - AUTO CYCLE
105		145	VALVE CONTROL - MODE 2
106		146	VALVE/TIMER CONTROL - MODE 2
107		147	LAMP CONTROL - FLASHER
110		150	REC STRG FLAG
111		151	FILL (DEV) FLAG
112		152	RECDEV FLAG
113		153	DRAIN (DEV) FLAG
114		154	
115		155	RESET CYCLE - FLASHER
116		156	
117		157	
120		160	
121		161	
122		162	
123		163	
124		164	
125		165	

A-3. EPTAK-100 SPECIAL FUNCTION RELAY ASSIGNMENT SHEET

APPLICATION: HDL - TEMPO : D.I. SYSTEM CONTROLLER (REV. 3) [R.C. Lamb 9/17/87]

RELAY ADDRESS	FUNCTION	RELAY ADDRESS	FUNCTION
70		74	
71		75	
72	(50 ms PULSE TRAIN) COUNT INPUT to #460		

APPENDIX A

A-4. EPTAK-100 TIMER ASSIGNMENT SHEET

APPLICATION: HDL - TEMPO: D.I. SYSTEM CONTROLLER (REV. 3)

TIMER NUMBER	SET POINT	START INPUT	RESET INPUT	OUTPUT ADDRESS	FUNCTION
450	004	140	140	450	VALVE CLOSE DELAY
451	3.5	431/432 433/434	142	451	PUMP START DELAY
452	1.5	460	141	452	FLASHER OFF DELAY
453	008	404	140 142	453	FLOW ALARM DELAY
454	300	143 (150)	143 (146)	454	PUMP ON TIME - AUTOCYCLE
455	750	142 (150)	142 (146)	455	PUMP OFF (½) - AUTOCYCLE
456	005	142 (150)	142 (146)	456	VALVE CONTROL - AUTOCYCLE
457	750	455 (150)	455	457	PUMP OFF (½) - AUTOCYCLE

↑ SECONDS

A-5. EPTAK-100 COUNTER ASSIGNMENT SHEET

APPLICATION: HDL-TEMPO: D.I. SYSTEM CONTROLLER (REV. 3)

COUNTER NUMBER	SET POINT	COUNT INPUT	RESET INPUT	OUTPUT ADDRESS	FUNCTION
460	005	72 (141)	101 (155)	460	FLASHER- ON TIMER

5 x .05 SECS => 0.25 SECONDS ON TIME.

APPENDIX A

A-6. EPTAK-100 PROGRAM LIST

APPLICATION: HDL-TEMPO: D.I. SYSTEM CONTROLLER, Rev. 3 (RBlamb 9/17/87)

PROGRAM STEP NUMBER	COMMAND	ADDRESS	COMMENTS
00	LD	400	START - by START Pushbutton(s)
01	OR	150	LATCH - RECSTRG FLAG RELAY
02	ANI	402	IF TRUE (Binary ϕϕ), then is
03	ANI	403	REC. STORAGE FUNCTION REQUEST
04	ANI	141	RESET - by STOP Pushbutton(s)
05	OUT	150	FLAG - RECIRC STORAGE FCN.
06	LDI	147	'DAS BLINKEN LIGHTS' CONTROL RELAY
07	ORI	430	STEADY FCN. LAMPS, when PUMP⇒OFF
08	ANB		AND 'em together
09	OUT	435	LAMP(S) DRIVER - RECSTRG
10	LD	400	START P.B.
11	OR	151	LATCH - FILL FLAG
12	ANI	402	IF TRUE (Binary ϕ1), then is
13	AND	403	FILL DEVICE FCN. RQST.
14	ANI	141	RESET
15	OUT	151	FLAG - FILL FCN.
16	LDI	147	'BLINK de LIGHTS'
17	ORI	430	STEADY LAMPS when PUMP off.
18	ANB		Logical AND
19	OUT	436	LAMP DRVR. - FILL (DEVICE)
20	LD	400	START P.B.
21	OR	152	LATCH - RECDEV FLAG
22	AND	402	IF TRUE (Binary 1ϕ), then is

A-6. EPTAK-100 PROGRAM LIST (cont'd)

APPLICATION: HDL- TEMPO: D.I. SYS. CONTROLLER (Pg. 2/7)

PROGRAM STEP NUMBER	COMMAND	ADDRESS	COMMENTS
23	ANI	403	RECIRC DEVICE FCN. RQST.
24	ANI	141	RESET
25	OUT	152	FLAG - RECDEV FCN.
26	OUT	437	RECDEV LAMP(S) & D.A. AUTO-START {CAN'T BLINK}
27	LD	400	$\boxed{\text{START}}$ P.B.
28	OR	153	LATCH - DRAIN FLAG
29	AND	402	IF TRUE (Binary 11) then is
30	AND	403	DRAIN DEVICE FCN. RQST.
31	ANI	141	RESET
32	OUT	153	FLAG - DRAIN FCN.
33	LDI	147	'BLINKEN DAS LIGHTS'
34	ORI	430	STEADY LAMPS if PUMP off.
35	ANB		Logical AND
36	OUT	441	LAMP(S) DRIVER - DRAIN (DEVICE)
37	LD	442	LOOK FOR FLOW ALARM FLAG
38	OR	401	LOOK FOR $\boxed{\text{STOP}}$ Pushbutton(s)
39	OR	140	LATCH - STOP FLAG RQST.
40	ANI	400	RESET - by START P.B.
41	OUT	140	STOP - REQUEST FLAG RELAY
42	LD	140	START the VALVE CLOSE DELAY TIMER
43	OUT	450	TIMER - DELAYED VALVE CLOSURE
44	(K)	004	4 SECONDS AFTER PUMP STOPS
45	LD	450	ACTIVATE THE DELAYED STOP RELAY

APPENDIX A

A-6. EPTAK-100 PROGRAM LIST (cont'd)

APPLICATION: HDL-TEMPO: D.I. SYS. CTRLLR (Pg. 3/7)

PROGRAM STEP NUMBER	COMMAND	ADDRESS	COMMENTS
46	NOP ~~OR~~	~~141~~	~~LATCH - DELAYED STOP RELAY (PREVENTS RESTART -)~~
47	NOP ~~ANI~~	~~401~~	~~RESET - STOP P.B. before a RE-START~~
48	OUT	141	FLAG - DELAYED STOP (VALVES CLOSE)
49	LD	150	RECSTRG ?? } Logical OR
50	OR	151	FILL ??
51	ANI	144	VALVE CONTROL - RECSTRG AUTO-CYCLE
52	OUT	431	OPEN V1 - STORAGE SUCTION VALVE
53	LD	152	RECDEV ?? } Logical OR
54	OR	153	DRAIN ??
55	OUT	432	OPEN V2 - DEVICE SUCTION VALVE & ACTIVATE BOOSTER PUMP RLY.
56	LD	151	FILL ?? } Logical OR
57	OR	152	RECDEV ??
58	OUT	433	OPEN V3 - DEVICE DISCHARGE VALVE
59	LD	150	RECSTRG ?? } Logical OR
60	OR	153	DRAIN ??
61	ANI	144	VALVE CONTROL - RECSTRG AUTO-CYCLE
62	OUT	434	OPEN V4 - STORAGE DISCHARGE VALVE
63	LD	150	RECSTRG ??
64	OR	151	FILL ?? } LOGICAL OR
65	OR	153	DRAIN ??
66	ANI	144	VALVE CONTROL - RECSTRG AUTO-CYCLE
67	ANI	145	VALVE CONTROL - MODE2 - FILL/DRAIN
68	ANI	146	VALVE CONTROL - MODE2 - RECSTRG

A-6. EPTAK-100 PROGRAM LIST (cont'd)

APPLICATION: HDL-TEMPO: D.I. SYS. CTRLR (Pg. 4/7)

PROGRAM STEP NUMBER	COMMAND	ADDRESS	COMMENTS
69	OUT	443	OPEN V5 - D.I. TANKS BYPASS LOOP
70	LD	431	V1 OPEN ? } SUCTION SIDE
71	OR	432	V2 OPEN ? } LOGICAL OR
72	LD	433	V3 OPEN ? } DISCHARGE SIDE
73	OR	434	V4 OPEN ? } LOGICAL OR
74	ANB		AND (LOGICAL) 'em together {MUST HAVE ONE EACH SIDE}
75	ANI	142	RESET TIMER on each PUMP STOP (AUTO-CYCLE)
76	OUT	451	TIMER - DELAYED PUMP START
77	(K)	3.5	3.5 SECS AFTER VALVES OPEN {ALLOWS for CORRECT RE-START}
78	LD	451	ACTIVATE MAIN PUMP START RELAY
79	ANI	140	INSTANT STOP of PUMP ON STOP P.B.
80	ANI	142	AUTO-CYCLE PUMP CONTROL
81	OUT	430	START the MAIN D.I. PUMP
82	LD	150	← BEGINNING of RECSTRG AUTO-CYCLE ←
83	ANI	143	'RESET' - TIMED - STARTS/STOPS RUN TIMER
84	ANI	146	MODE 2 - RESETS - MAKES CONT. RUN
85	OUT	454	TIMER - PUMP • RUN TIME • AUTO-CYCLE
86	(K)	300	5 minutes RUN TIME per CYCLE
87	LD	454	ACTIVATE AUTO-CYCLE PUMP RELAY
88	OUT	142	FLAG/RELAY - STOPS PUMP when - ON -
89	LD	150	RECSTRG MODE/FCN ONLY!
90	AND	142	STARTS/RESETS - OFF TIMER(S)
91	ANI	146	MODE 2 - LOCKOUT (RESETS) OFF TIMERS

APPENDIX A

A-6. EPTAK-100 PROGRAM LIST (cont'd)

APPLICATION: HDL-TEMPO: D.I. SYS. CTRL'R (pg. 5/7)

PROGRAM STEP NUMBER	COMMAND	ADDRESS	COMMENTS
92	OUT	455	TIMER - PUMP OFF TIME (1 of 2)
93	(K)	750	12.5 MINUTE OFF TIME (1st SEGMENT)
94	LD	150	RECSTRG FCN. ONLY!
95	AND	455	CASCADE THE TIME DELAY(S)
96	OUT	457	TIMER - PUMP OFF TIME (2 of 2)
97	(K)	750	12.5 MINUTE OFF TIME (2nd SEGMENT)
98	LD	457	ACTIVATE RE-CYCLE RELAY (RESET)
99	OUT	143	RE-STARTS RUN TIMER after 25MIN OFF
100	LD	150	RECSTRG FCN. ONLY!
101	AND	142	PUMP OFF STARTS TIMER
102	ANI	146	MODE 2 - LOCKSOUT VALVE CLOSE TIMER
103	OUT	456	TIMER - DELAYED VALVE CLOSE V1,V4,V5 & AUTO-CYCLE
104	(K)	005	5 SECONDS AFTER PUMP STOPS, (EACH CYCLE)
105	LD	456	ACTIVATE VALVE CONTROL RELAY
106	OUT	144	END OF ? AUTO-CYCLE VALVE OPEN/CLOSE (V1, V4, V5)
107	LDI	404	FLOW SWITCH INPUT - OPEN on NO FLOW
108	ANI	140	RESET - ON NORMAL STOP
109	ANI	142	RESET - ON AUTO-CYCLE STOP
110	OUT	453	TIMER - FLOW ALARM DELAY
111	(K)	008	8 SECONDS - MAX. TIME for D.A. w/o FLOW.
112	LD	453	ACTIVATE FLOW ALARM RELAY
113	OR	442	LATCH - "ALARM" STAYS ON till RESET

A-6. EPTAK-100 PROGRAM LIST (cont'd)

APPLICATION: HDL-TEMPO: D.I. SYS. CTRL'R (Pg. 6/7)

PROGRAM STEP NUMBER	COMMAND	ADDRESS	COMMENTS
114	ANI	401	RESET FLOW ALARM - by - STOP P.B. ONLY!
115	OUT	442	DRIVER - FLOW ALARM LAMPS
116	LD	400	START P.B. - INITATE MODE 2
117	AND	430	ONLY AFTER 3.5 SEC - PUMP MUST BE ON
118	LD	146	MODE 2 ◆ AUTO-CYCLE DEFEAT RELAY (LATCH)
119	ORB		OR 'em together (LOGICAL OR)
120	AND	150	MUST be in RECSTRG FCN.
121	OUT	146	KILL AUTO-CYCLE (STEADY RECIRC STRG & NO D.I. BYPASS)
122	LD	400	MODE 2 ◆ INIT. by START P.B.
123	AND	430	PUMP MUST BE ON (3.5 SEC DELAY)
124	LD	145	MODE 2 ◆ FILL/DRAIN BYPASS DEFEAT (LATCH RELAY)
125	ORB		Logical OR
126	LD	151	FILL? } LOGICAL OR
127	OR	153	DRAIN? } MUST be ONE OR OTHER
128	ANB		AND 'em together (Both OR branches)
129	OUT	145	MODE 2 ◆ FILL/DRAIN NOW thru D.I. TANKS
130	LD	155	RESET - RESTARTS LIGHT ON COUNTER
131	PLS	101	SINGLE SHOT RESET PULSE SOURCE
132	LD	101	INITIATE COUNTER RESET
133	RST	460	RESET COUNTER (LAMP ON TIMER)
134	LD	72	50 m Sec PULSE TRAIN SOURCE
135	ANI	141	'RESETS' @ DELAYED STOP TIMEOUT
136	OUT	460	FCN. LAMP(S) ON TIMER (COUNTER)

APPENDIX A

A-6. EPTAK-100 PROGRAM LIST (cont'd)

APPLICATION: HDL-TEMPO: D.I. SYS. CTRL'R (Pg. 7/7)

PROGRAM STEP NUMBER	COMMAND	ADDRESS	COMMENTS
137	(K)	005	250 mSec ON TIME
138	LD	460	INITIATE END OF LAMP ON TIME
139	OUT	147	LAMP FLASHER CONTROL (ON/OFF)
140	LD	460	INITIATE OFF TIMER COUNTDOWN
141	ANI	141	'RESETS' @ DELAYED STOP TIMEOUT
142	OUT	452	TIMER-FCN. LAMPS OFF TIME
143	(K)	1.5	1.5 SECOND OFF TIME (~ 14% DUTY ~)
144	LD	452	INITIATE 'DAS BLINKEN LIGHTS' RE-CYCLE
145	OUT	155	FLASHING LAMPS RESET RELAY
146			END of PROGRAM RC Lamb 9-17-87

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